AD-A071 181 NAVY ELECTRONICS LAB SAN DIEGO CA F/G 17/1
AN EVALUATION OF THE OPERATIONAL EFFECTIVENESS OF THE PROPOSED --ETC(U)
JUN 66 C H STURTEVANT, W H FRYE, L A HARVEY
UNCLASSIFIED NEL-TM-942 NL

| OF |
AD
A071181

END
DATE
FILMED
8 -79
DDC

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED UNCLASSIFIED

~~CONFIDENTIAL~~

LEVEL II

U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA • A BUREAU OF SHIPS LABORATORY

This is a working paper giving tentative information about some work in progress at NEL. If cited in the literature the information is to be identified as tentative and unpublished.

B.S. 9

MOST Project -1 (ASW-21)

AD A071181 000727

DDC FILE COPY

Good

(12) 54p.

File

TECHNICAL MEMO[redacted] TM-942

(9)

NEL/Technical Memorandum (6)

AN EVALUATION OF THE OPERATIONAL EFFECTIVENESS OF THE PROPOSED PAIR AUTOMATIC NON-ALERTING TRANSMISSION MODES. ~~(U)~~

(11) 3 Jun[redacted]66

(10) C. H. Sturtevant, W. H. Frye and L. A. Harvey (Code 3320)

S 27-20 (8573)
~~NEL~~ J71461

NEL/Technical Memorandum 942

(14) NEL-TM-942

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

25

253 550 Gm

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. The transmission or the revelation of its contents, in any manner to an unauthorized person is prohibited by law.~~

~~Extracts from this publication may be made to facilitate the preparation of other Department of Defense Publications. It is forbidden to make extracts for any other purpose without the specific approval of the Chief of the Bureau of Ships, except as provided for in the U.S. Navy Security Manual for Classified Matter.~~

DOWNGRADED AT 3-YEAR INTERVALS • DECLASSIFIED AFTER 12 YEARS • DOD DIR 5200.10

UNCLASSIFIED UNCLASSIFIED

~~CONFIDENTIAL~~

942 000727

6-3

Cat 118880 - (118881 - ASW 2113)

UNCLASSIFIED

~~CONFIDENTIAL~~

TECHNICAL MEMORANDUM

AN EVALUATION OF THE OPERATIONAL EFFECTIVENESS OF THE PROPOSED PAIR AUTOMATIC NON-ALERTING TRANSMISSION MODES (U)

C. H. Sturtevant

W. H. Frye

L. A. Harvey

This memorandum constitutes a portion of the work on NEL Problem J714, AN/SQS-23 Modernization Program, and attempts to answer some specific questions posed by program personnel. It should not be construed as a formal report; only a limited outside distribution is intended.

~~CONFIDENTIAL~~

UNCLASSIFIED

UNCLASSIFIED
~~CONFIDENTIAL~~

INTRODUCTION

Studies have been conducted in response to a request for analysis of the following AN/SQS-23 PAIR program tasks.

1. Analyze the operational effectiveness of the proposed PAIR automatic non-alerting modes under a variety of tactical situations.

2. From a tactical standpoint, determine how much a ship compromises its situation by:

   ~~a.~~ alerting,

   ~~b.~~ giving range, and

   ~~c.~~ giving own heading.

3. Analyze the ability of PAIR to interface properly with ASROC (Mk 111 and Mk 114) when in the non-alerting modes, i.e., adequate data rates, tracking accuracies, etc.

4. Determine minimum ship spacing with PAIR.

UNCLASSIFIED
~~CONFIDENTIAL~~

TASK I

Task Statement

Analyze the operational effectiveness of the proposed PAIR automatic non-alerting modes (ANAM) under a variety of tactical situations.

Study Results

ANAM \ Tactical Situations	Hot War, Deep, Escort, Defensive	Hot War, Shallow Patrol, Offensive	Cold War, Shallow, Patrol, Offensive
Single Frequency	Marginal	Acceptable	Marginal
Dual Frequency	Acceptable	Acceptable	Acceptable

Analysis Procedures

This task was divided into the several subtasks:

1. Definition of "operational effectiveness" as system performance measure for sonar.
2. Selection of appropriate tactical situations to adequately exercise the various sonar system options.
3. Computation of coverages available within the selected tactical situations.
4. Computation of the required coverages as a function of threat, weapon type, and probability of target kill.
5. Summarization of data for PAIR coverage performance.
6. General comments about the relative effectiveness of the two non-alerting modes and manual modes for detection, classification, and tracking.

In analysis procedures 1-5 the model above is applied to measure absolute effectiveness of the auto non-alerting modes; procedure 6 discusses relative effectiveness by comparing auto non-alerting mode performance and manual performance.

Performance Measure Definition

An appropriate measure of system effectiveness (MOSE) is required to gauge the performance of the subject system in performing the sequence of functions required for the misssion. A commonly accepted measure for undersea/surface warfare systems is the Weapon System Effectiveness (WSE) concept adopted by ComSubPac, ComSubLant, ASWForPac, etc. This measure, stated simply, is the "probability chain."

$$WSE = P_D \; P_C \; P_T \; P_K$$

where:

P_D = Probability of Detection

P_C = Probability of correct classification given detection.

P_T = Probability of Tracking, given classification

P_K = Probability of Kill, given acquisition

In this study the probability of detection is assumed to be 1.0 for a range at which the single ping probability is 50 percent (Table 1 shows 50 percent detection ranges (R_D) which were derived from reference 1). The probabilities of classification and tracking are assumed to be unity if the respective time requirements of each function are met. Probability of kill is assumed to be synonymous with probability of weapon acquisition of the target.

By definition, coverage performance is the ratio of time available to perform the required functions to the time required for these functions. The time available is a function of sonar range, unit spacing, point of intended movement, ownship speed and course, and target speed and course. The time required is a function of the time needed to perform the sonar surveillance functions of detection, classification, and tracking for an acceptable probability of target kill. Therefore, this measure of coverage performance is influenced by sonar parameters and data rate.

Expressed symbolically:

$$(1)\quad \text{Coverage Performance } (C_P) = \frac{\text{Time Available } (T_A)}{\text{Time Required } (T_R)}$$

This function takes on the following values:

$$(2)\quad C_P = \begin{cases} 1 & \text{if } T_A \geq T_R \\ T_A/T_R & \text{if } T_A \leq T_R \\ 0 & \text{if impossible due to some physical constraint} \end{cases}$$

Figure 1 provides a schematic of the C_P computation.

Tactical Situation Selection

Selection of the "appropriate-tactical situations" to exercise the various sonar system options adequately was based on data from an earlier study, (Reference 2) wherein the ASW mission was identified and rated as to importance in cold and limited war. Consideration of possible enemy actions, war states, geophysical characteristics, mission role, and ASW ship posture (Table 2) has led to a classification of the spectrum of ASW missions into three categories (Table 3). The first two categories exercise the capability to deliver ordnance to the enemy (hot war), hence

they cover the "weapon delivery" aspect of the performance measure. Category 3 contains elements of both 1 and 2. Operations in this category are related to ASW barriers and HUK groups against targets which are generally attempting to avoid detection. Much ASW activity centers around trailing operations, and thus the ability to track and maintain contact. It is for these reasons that Category 3 was not analyzed specifically under the C_P criteria. Instead, inferences were drawn from the results obtained in analyzing situations 1 and 2 from Task 3 results, and from the general comments listed at the end of this section. Table 4 summarizes nominal submarine parameters as a function of its operation. Table 5 shows the enemy and own force performance options chosen for the tactical situations analyzed.

<u>Computation of Available Time</u>

The available time is determined from the width of the sonar surveillance zone and the relative penetration speed of a transitor or intruder who is attempting to minimize his exposure time. A frontal penetration along the minimum sonar crossing line (MCL) represents a "worst" case for the ASW screening unit. The MCL is a function of the sonar detection range, R_D, and the screen spacing factor, k_s.

Figure 3 shows two models: Model 1 represents an overlapping screen used to analyze Situation 1, and Model 2 represents a loose screen which employs random patrol areas, used to analyze Situation 2. Figures 4 and 5 provide the individual zone width (Z) for close screen (spacing $\leq 2R_D$) and loose screen (spacing $\geq 2R_D$) configuration, respectively. An axial penetration through the screen's center front enables the penetrator to add his speed to the SOA for a relative crossing speed, W, of:

$$W = V_{sub} + SOA$$

$$= V_{sub} + V_{screen}$$

Available time is expressed as:

$$T_{avail} = \frac{Z}{W}$$

Computation of Required Time

The "required time" is a direct function of the time necessary to classify and gain a firm track (assuming that the decision time for weapon assignment is negligible). If the tracking time needed for an adequately delivered weapon is equal to or less than the classification time, the classification time is the "required time." If otherwise, the tracking time is the "required time."

Probability of weapon acquisition, P_a, is expressed as a function of prediction-to-tracking time ratio, P_r, and the bias error, b_r, (homing) range and fire control error (sonar and weapon delivery CEP). Note that this does not influence C_P.

Figure 6 illustrates typical values of P_a for ASROC system parameters.

The flight time for weapons not having midcourse guidance constitutes the prediction time (time over which no target information can be used to redirect the launched weapon). Table 6 provides a listing of weapon launch to intercept times.

Classification time is a function of the number of pings required to produce a threshold number of clues. Values assumed for this study are shown in Figure 7 for hard-to-classify targets.

Since the models implemented resulted in a predetection-to-tracking time ratio $p_r = 1$ the classification time was assumed always to be larger then the tracking time.

Times for the case studies were determined by reference to the proposed PAIR single and dual non-alerting modes, Tables 7 and 8 or Figure 8 .

PAIR Coverage Performance

Results from the case studies of the general tactical situations are shown in Tables 9 and 10. Table 9 shows that PAIR coverage performance for Tactical Situation 1 is relatively good for a 6 knot penetrator, (i.e., 21 out of 24 cases with unity performance). Against the 30 knot penetrator the score is less, being 3 out of 6 unity ratios for dual mode/hard classification cases against zero out of 6 unity ratios for the single mode/hard classification cases. The picture is considerably better for the easy classification cases.

Case studies of Tactical Situation 2 reflect the better sonar ranges. (In layer versus below layer for Situation 1). Table 10 shows C_p values of unity for all cases except when the single frequency mode is utilized and the spacing factor is 10 or greater.

General Comments about the Two Non-Alerting Modes

The comments listed are with respect to the relative effectiveness of the non-alerting modes and the manual mode in performing the functions of detection, classification and tracking.

DETECTION

Single Frequency Mode

Unless single ping detections can be assured the detection process will be degraded because of the periodic gap in the search transmission sequence due to the insertion of the track/classify (T/C) sequence of transmissions. For some range scales settings this gap could also result in a poor time compressed display and a general lose in track continuity. In any case the time required for detection will be increased.

Dual Frequency Mode

Provided that track/classify transmissions do not interfere with the search operations this mode should result in an effective search-while-track mode of operation.

CLASSIFICATION

Single Frequency Mode

The T/C range scale setting is equal to or less than that of the search. Thus targets detected beyond the range scale setting of the T/C may not be effectively classified.

The gap between the T/C ping sequences can vary from 3.125 to 62.5 seconds which might result in an incoherent track. Also, many of the classification clues are derived from a sequence of observations; in this mode the sequence would be broken and thus the classification performance would be degraded.

Dual Frequency Mode

The T/C range scale setting is equal to or less than that of the search. Thus targets detected beyond the T/C range scale setting may not be effectively classified. However, if the situation demands this may be alleviated by a change in the operating mode.

TRACKING

Single Frequency Mode

The single frequency mode of transmission would degrade the tracking performance. The degration is prevalent in cases of:

(1) Large observation errors and/or

(2) Maneuvering targets.

However, in situations where the observation errors are small and the target is proceeding with a constant velocity the mode should generally proved adequate.

Dual Frequency Mode

The dual frequency mode of operation should be adequate. Since, if anything, it would enhance the data rate. The search keying interval would be set to the range scale just beyond the sonar range of the day and the track and classification (T/C) range scale setting would generally be one setting lower than the search setting. Folded range coverage provides tracking information when the T/C range scale setting is less than the search range scale setting.

Table 1 Ranges (kyd) For Single Ping Detection Probability of 0.5

Water Depth	SHALLOW WATER (100 fm)						DEEP WATER (1400 fm)					
Target Layer Position	IN			BELOW			IN			BELOW		
Ship Speed (kt) \ Target Str	10	15	20	10	15	20	10	15	20	10	15	20
20	14.3	15.9	17.8	1.2	1.4	1.90	14.3	15.8	17.8	1.2	1.4	1.90
15	16.5	18.1	20.0	1.4	1.6	2.13	16.5	18.0	20.0	1.4	1.6	2.13
12	18.7	20.3	22.2	1.59	1.81	2.36	18.7	20.2	22.2	1.59	1.81	2.36

Environmental Conditions:

1. All noise-limited
2. Sea State = 1.5
3. Layer Depth = 100'
4. Favorable Velocity Gradient

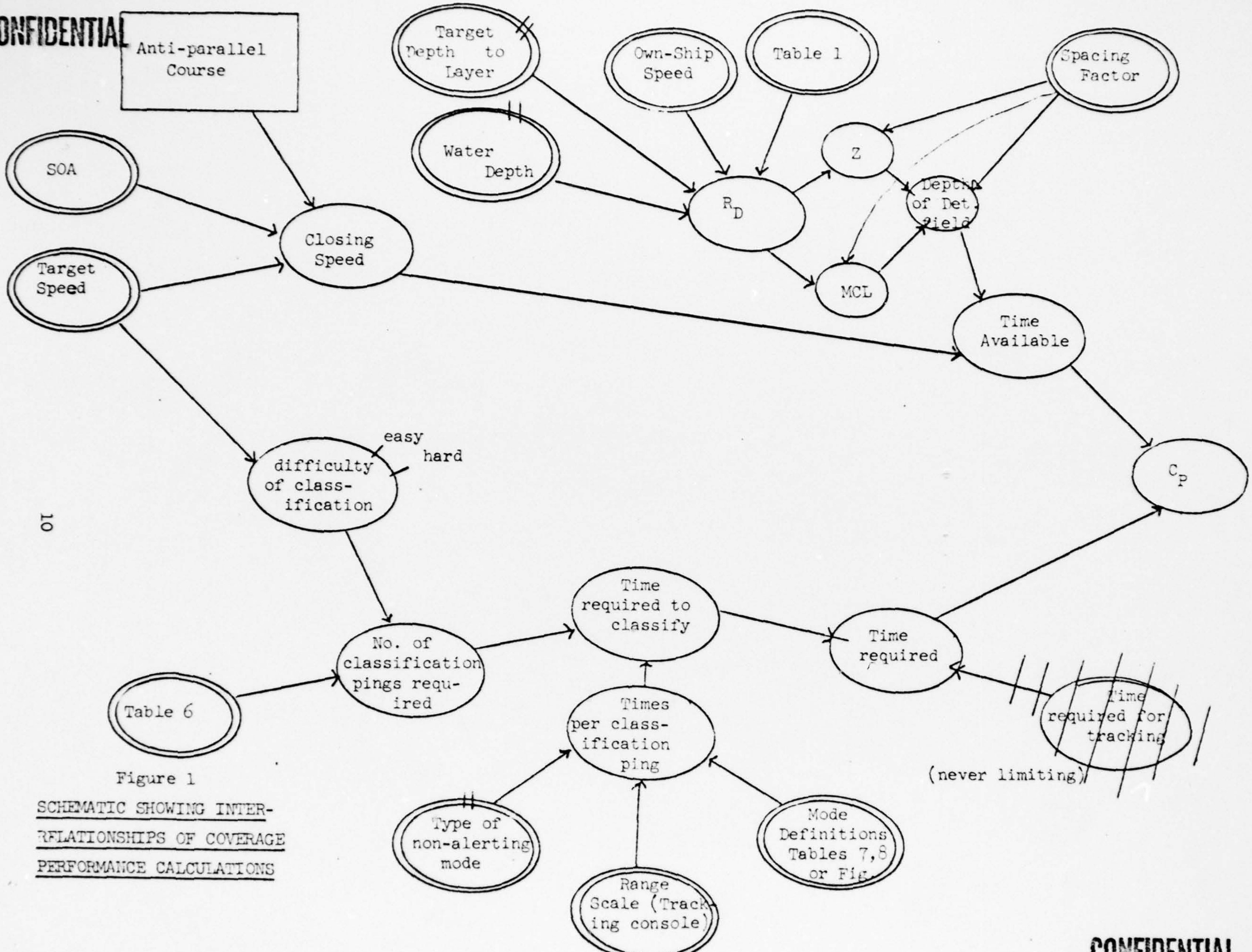


Figure 1

SCHEMATIC SHOWING INTERRELATIONSHIPS OF COVERAGE PERFORMANCE CALCULATIONS

Table 2

TACTICAL SITUATION TYPES

Type Situation	War Type	Geographic Area	Mission/ Role	ASW Ship Posture
1	Hot	Deep Water	Escort	Defensive
2	Hot	Shallow Water	Patrol	Offensive
3	Cold	Shallow Water	Patrol	Offensive

Table 3

MISSION SPECTRUM BY SITUATION
TYPE CATEGORIES

Situation Type

MISSION	1	2	3	NOTES
Strike Force	X	X		
ASW Barrier		X	X	
Underway (URG) Replenishment Group	X			a
Hunter Killer (HUK)	X	X	X	b
Amphibious Landing Force (ALF)	X	X		
Convoy	X			a

[a] Applies to Situation Type 2 for the escorting role in the terminal area (e.g., convoy). ASW ship posture is defensive for this role.

[b] Applies to Situation Type 3 for the patrol role which includes transitions or embarkations in deep water.

Table 4

SUMMARY OF NOMINAL SUBMARINE PARAMETERS AS A FUNCTION OF OPERATION

Operation \ Parameter	Depth (feet)	Speed (knots)	Range (kyd)
Periscope Search	60	6	9-12 max.
Sonar Search	—	5: 15 marginal	—
Screen Penetration	See Figure	3-6	
Torpedo Firing	≤ 200	3-6	≤ 2000 preferred
Evasion	See Figure	Variable	NA

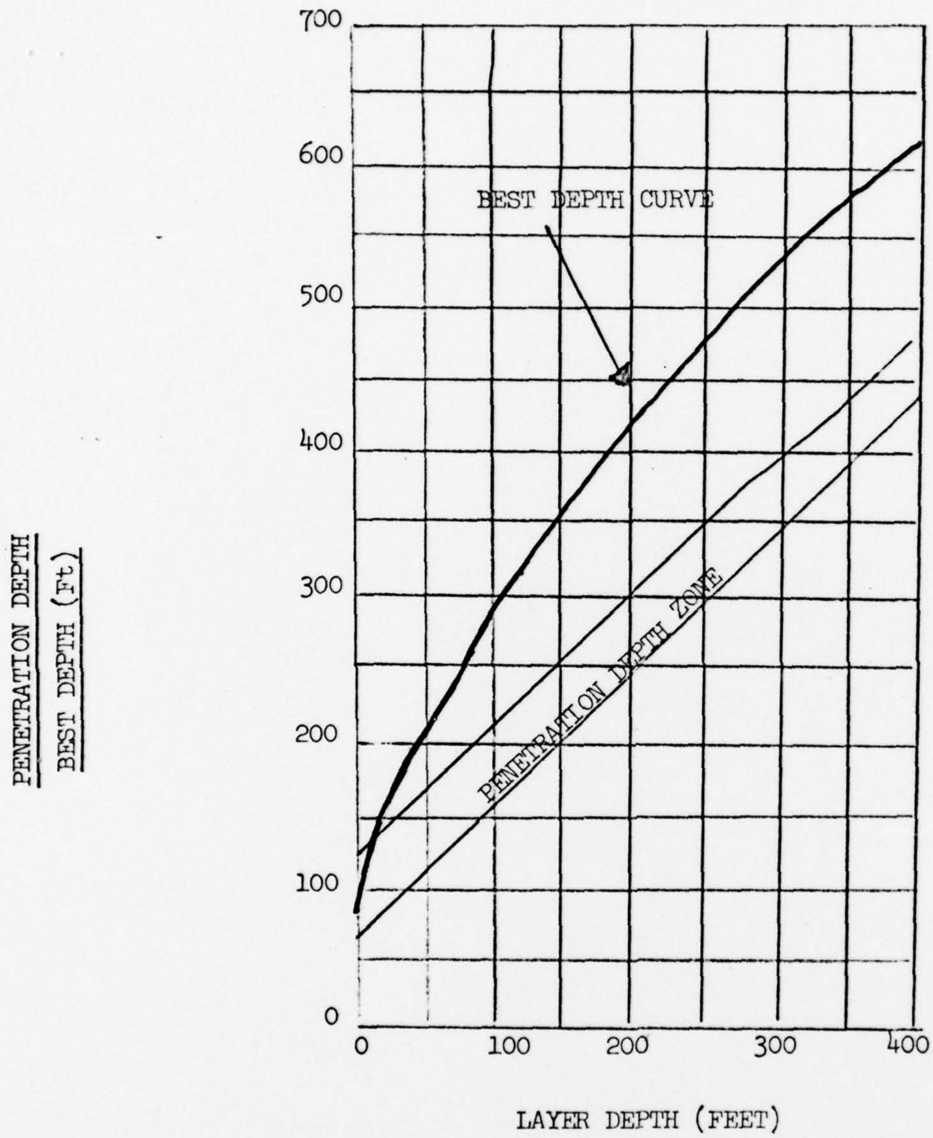


Figure 2 Layer Depth versus Submarine Penetration Depth and the Best Depth for the Submarine to Avoid Detection

Table 5

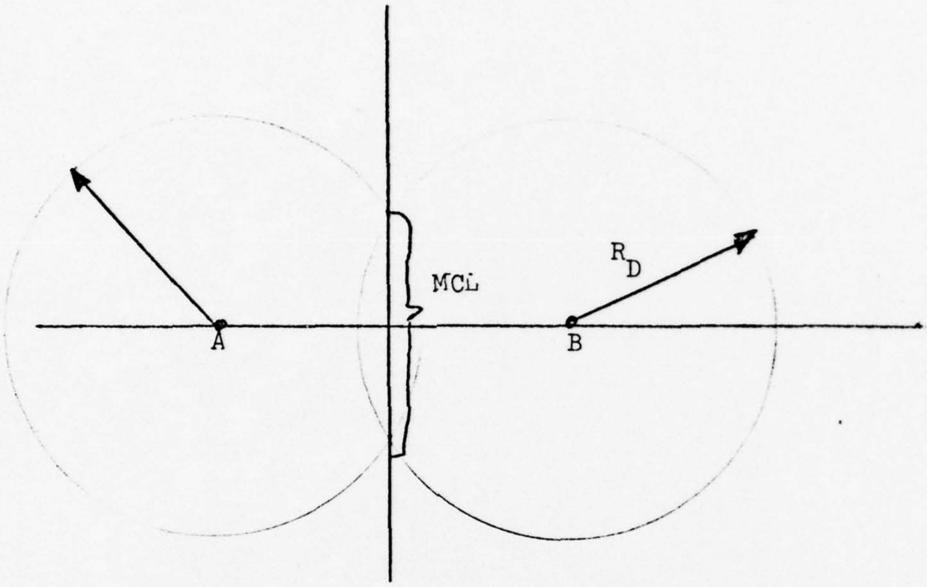
TACTICAL OPTIONS SELECTED FOR TARGET AND SCREEN EFFECTIVENESS COMPUTATIONS

Problem Description \ Situation	1	2	3
Model (See Figure 3)	1	2	2
Target Speed	6,30	6,30	30
Penetration Angle	0	0	0
Own Ship Speed	15,20	12	20
Target Depth	Penetration	Periscope	Best Depth
Detection Prob. (See Table 1)	1.4,1.4,1.4	18.7	1.90

Figure 3

ASW MODEL SCHEMATICS

Model 1



Legend

MCL = Minimum Crossing Line

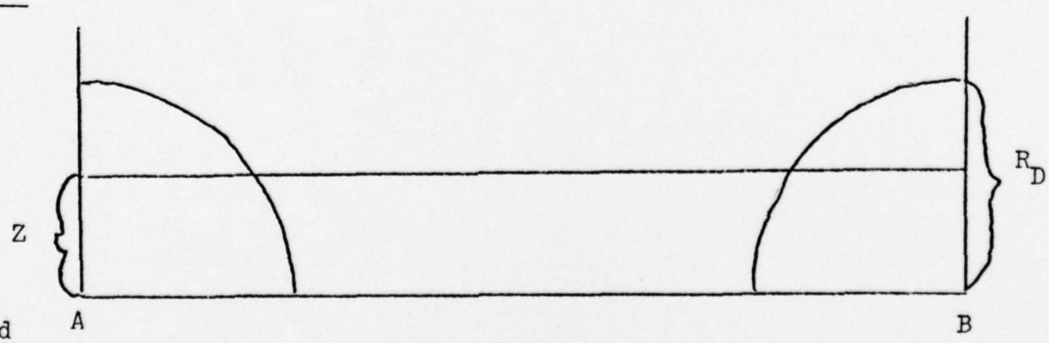
R_D = Effective Detection Range

Z = Effective Crossing Zone

A = Position of Ship A

B = Position of Ship B

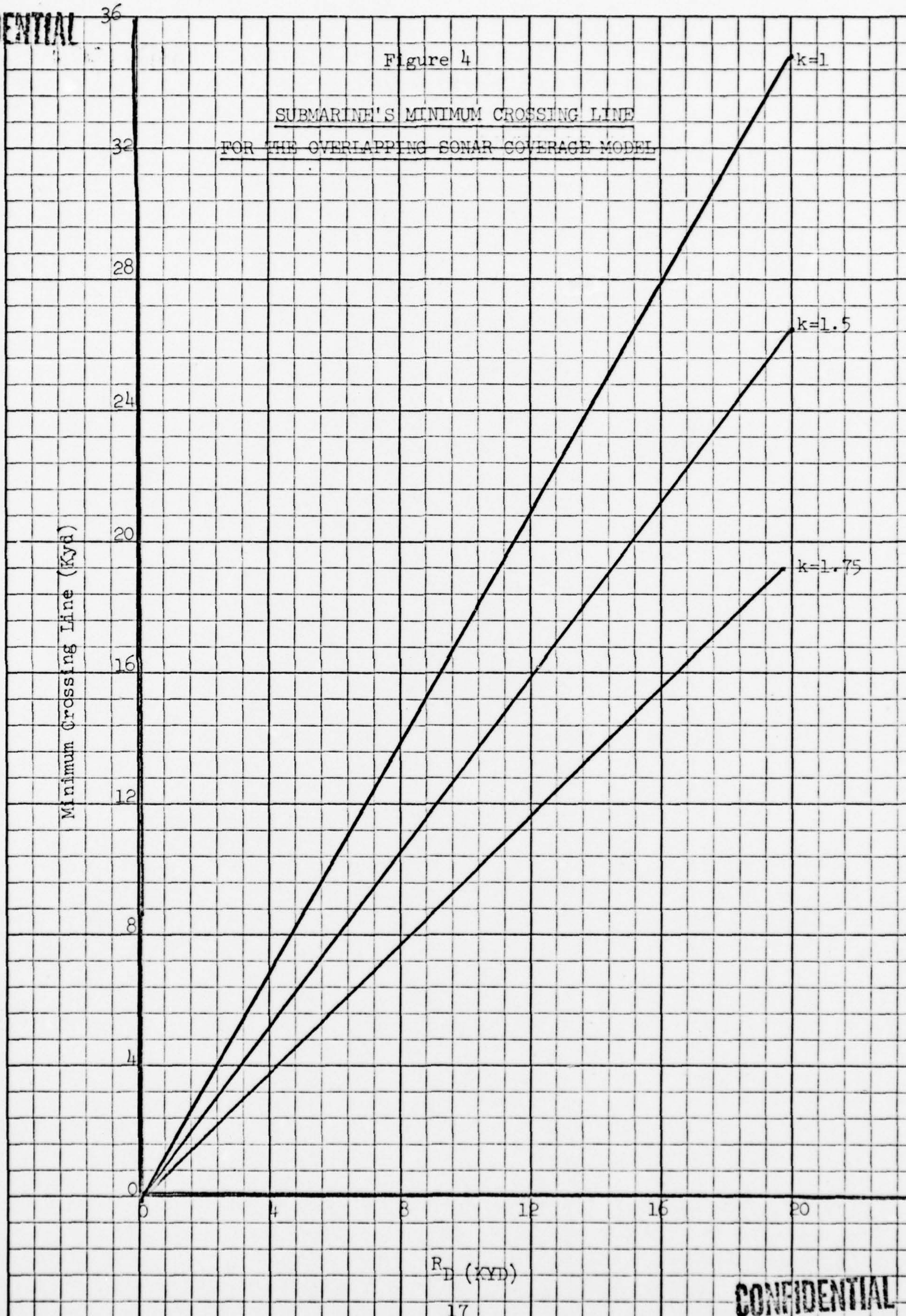
Model 2



Legend

Z is determined so that the area of the rectangle is equal to the area of the two quarter-circles.

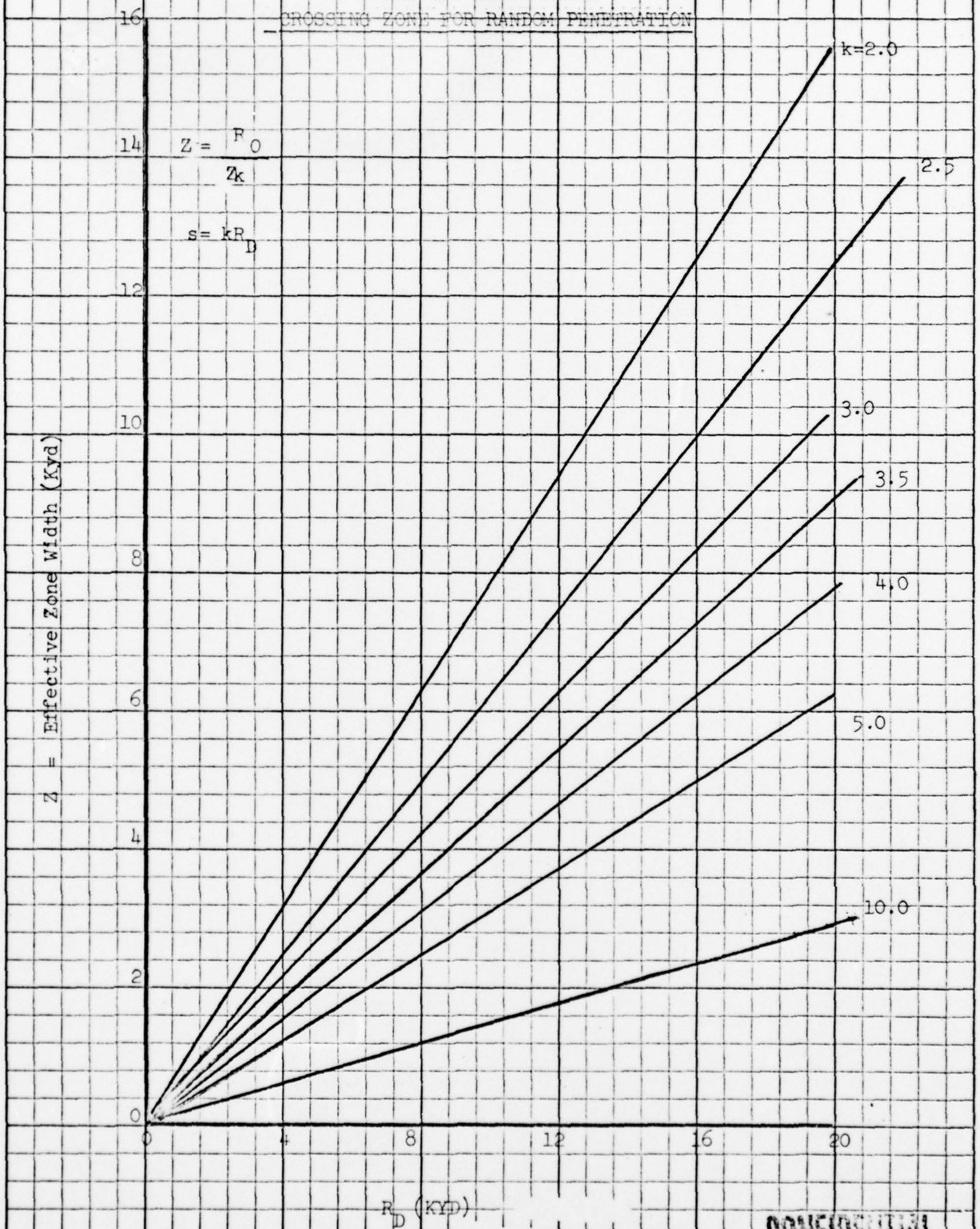
CONFIDENTIAL



CONFIDENTIAL

Figure 5

SUBMARINE'S EFFECTIVE CROSSING ZONE FOR RANDOM PENETRATION



CONFIDENTIAL

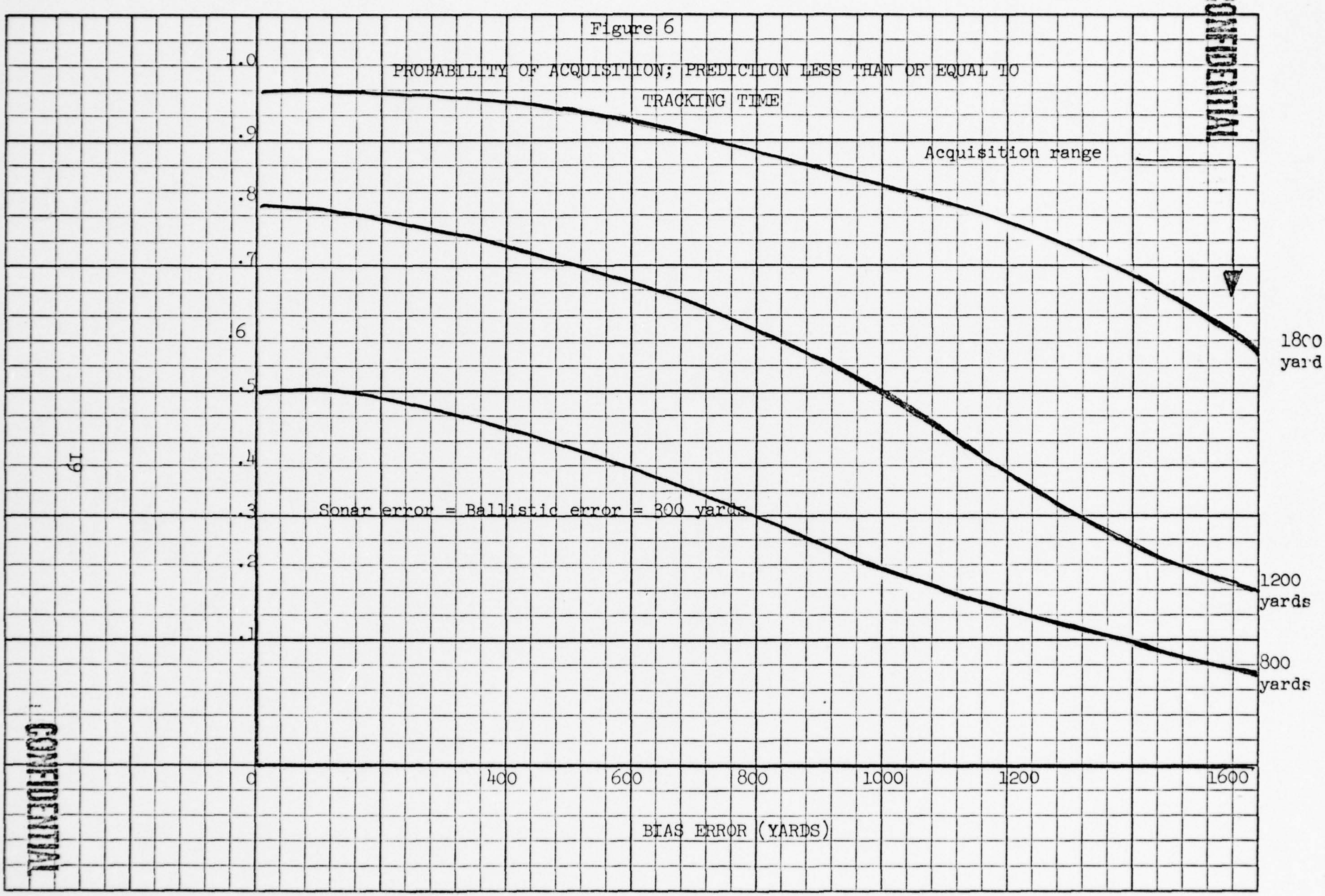


Figure 6

PROBABILITY OF ACQUISITION; PREDICTION LESS THAN OR EQUAL TO TRACKING TIME

CONFIDENTIAL

Table 6

WEAPON LAUNCH-TO-INTERCEPT TIME (SECONDS)

	Target Range to Launch (kdy)					
Weapon/Launcher	1.25	2.5	5.0	10.0	20.0	
Mk 46/Mk 32	50	100	200	-----	-----	
Mk 37/Mk 25	125 85	250 170	500 340	——	——	
ASROC/Mk 46	—	60	80	90	-----	Note a.
DASH/Mk 46	—	150	200	275	475	Note b.

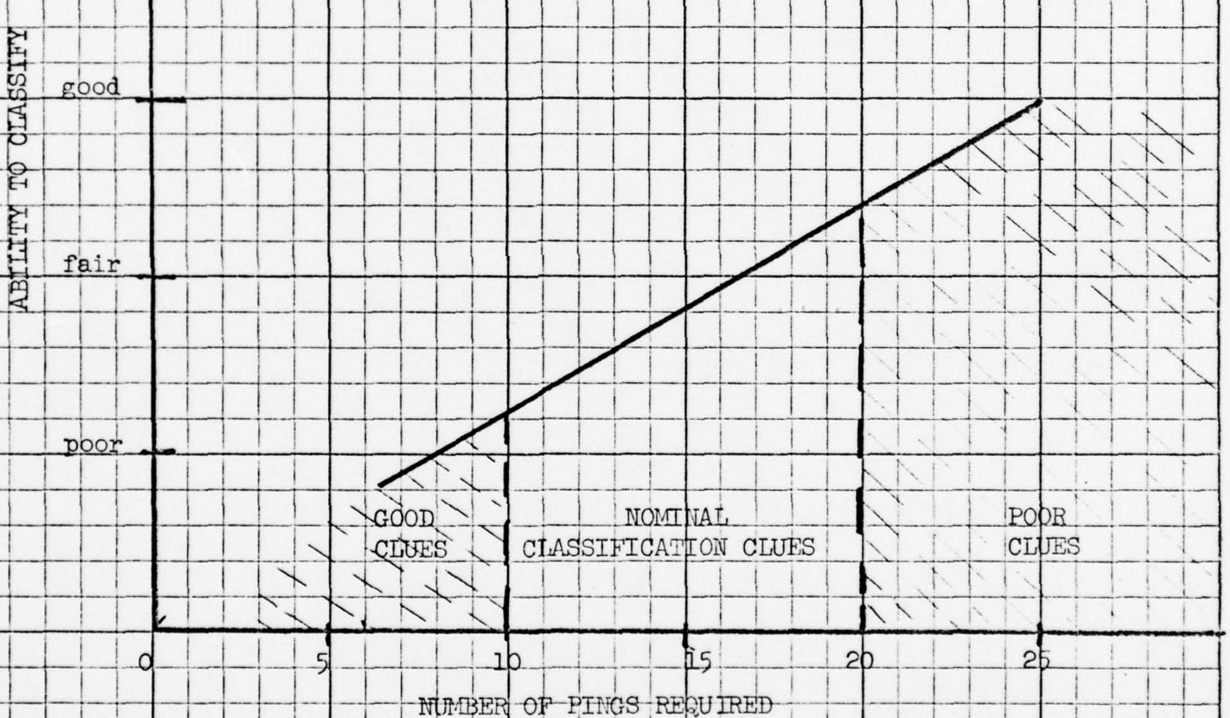
NOTES:

a. Includes 35 seconds average for torpedo acquisition and run-in to target.

b. Includes 35 seconds as above and the addition of 40 seconds average for fire control reaction and torpedo drop time. Hence, actual blind time is 75 seconds if DASH is guided to drop point.

Figure 7

Trade-off: Required Number of Pings Versus Difficulty of Classification



		TRACK/CLASSIFY											
		2.5			5			10			15		
OMNI	RDT	1	2	3	1	2	3	1	2	3	1	2	3
2.5	—												
5	—	3.125	2	6.25	6.25	1	6.25						
4	10				6.25	4	25	12.5	2	25			
4	20				6.25	6	37.5	12.5	3	37.5	18.75	2	37.5

Table 7

PING CYCLE DESCRIPTION: NON-ALERTING SINGLE FREQUENCY MODE OF TRANSMISSION

NOTE:
1. Ping Duration (seconds)
2. Number of pings in a sequence
3. Gap between sequence due to search transmission

SEARCH		TRACK/CLASSIFY							
		2.5		5		10		15	
OMNI	RDT	1	2	1	2	1	2	1	2
2.5	—								
5	—	3.125	6.25	6.25	6.25				
4	10			6.25	25	12.5	2.5		
4	20			6.25	37.5	12.5	36.5	18.75	37.5

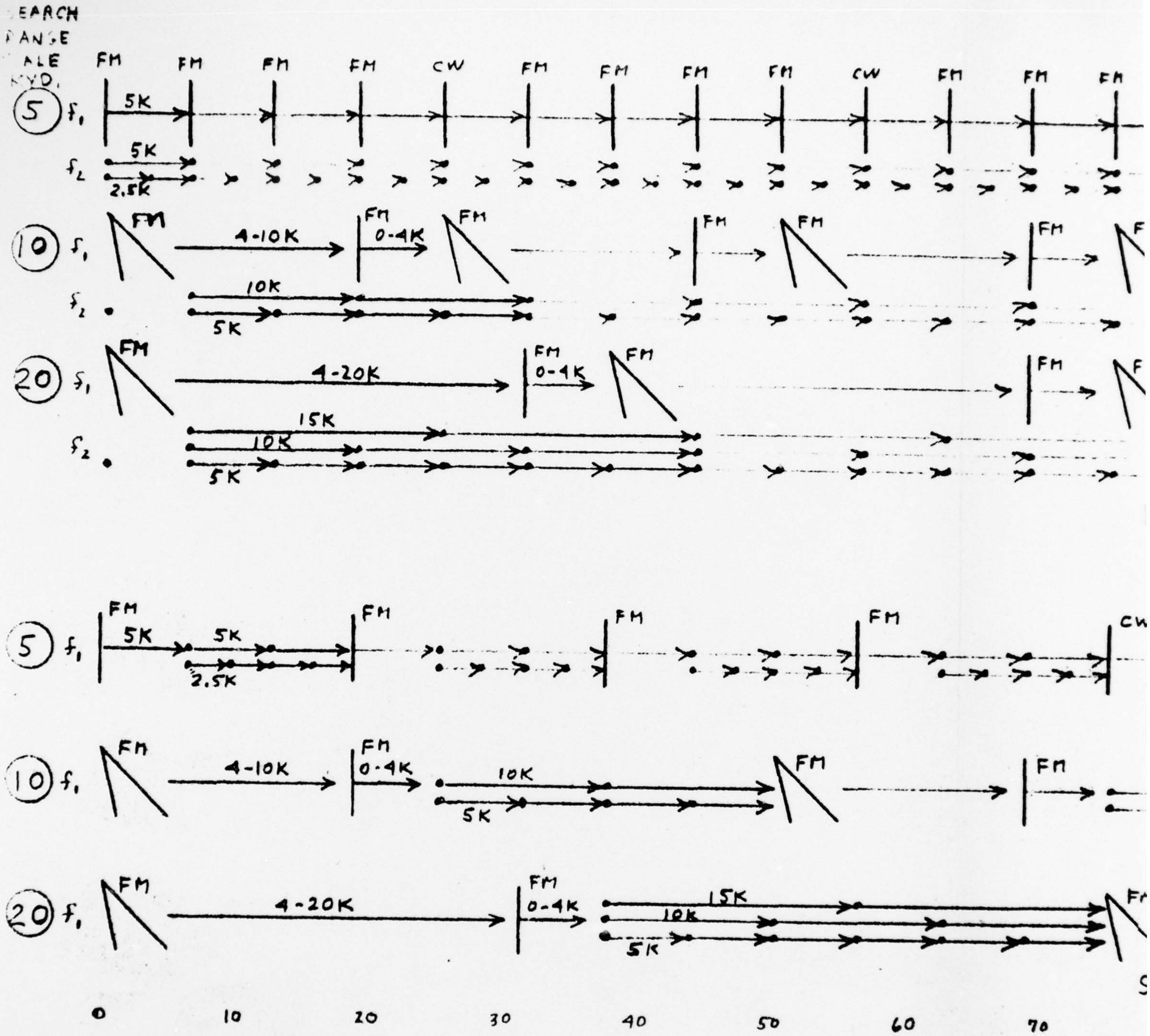
Table 8

PING CYCLE DESCRIPTION: NON-ALERTING DUAL FREQUENCY MODE OF TRANSMISSION

NOTE:

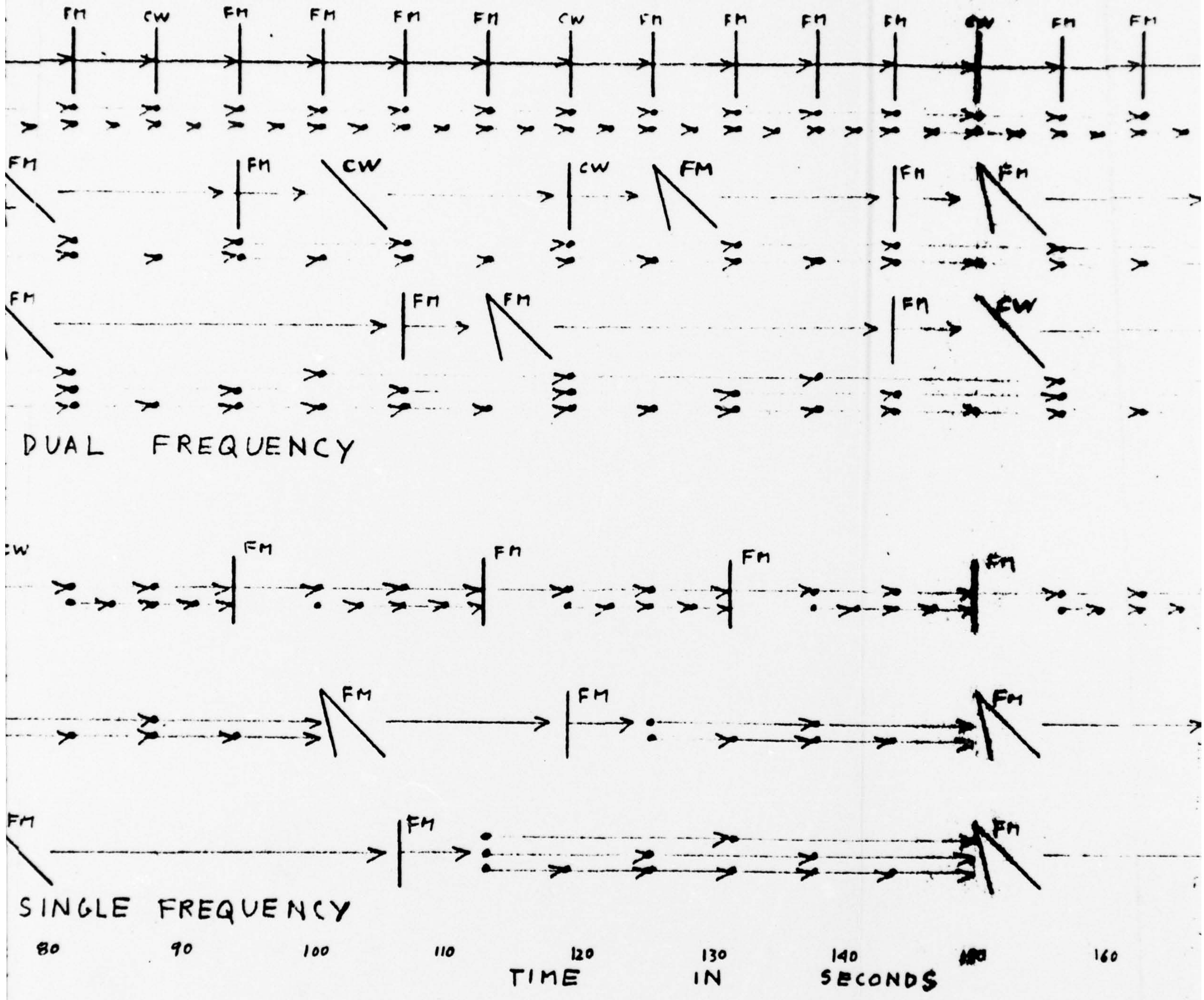
1. Track/classify: Ping Duration (seconds)
2. Search: Ping Duration (secands)

CONFIDENTIAL



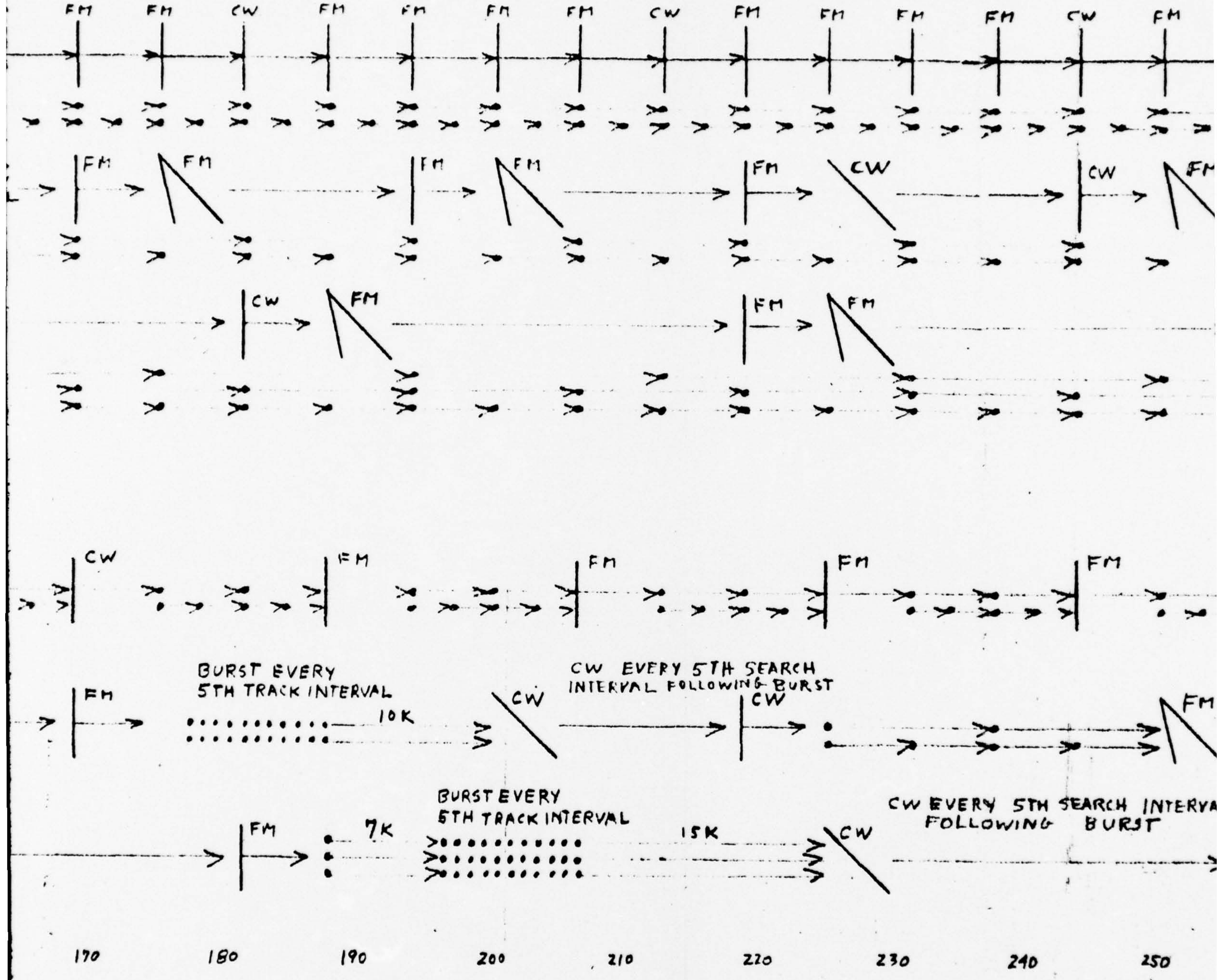
SEARCH
RANGE
SCALE
KYD.
FM
CW
5K
2.5K
4-10K
0-4K
10K
4-20K
15K
0
10
20
30
40
50
60
70

1


FM CW FM FM FM FM CW FM FM FM FM CW FM FM
DUAL FREQUENCY
SINGLE FREQUENCY
80
90
100
110
120
130
140
160
TIME IN SECONDS

2

page 24a



PAIR AUTOMATIC OPERATING SEQUENCES, NON-ALERTI

LEGEND:

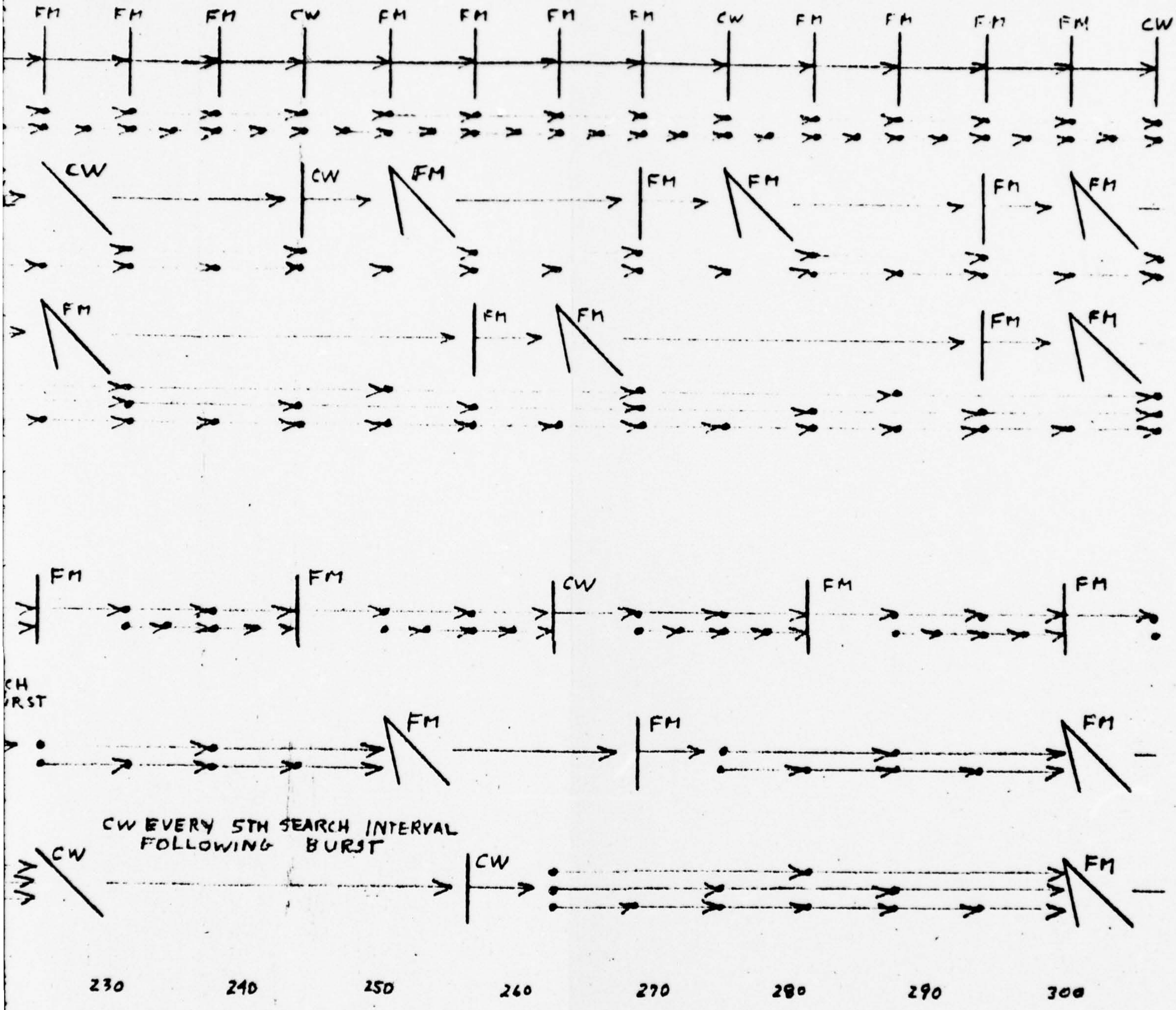
SEARCH ODT FM 128/32 UP/DOWN CW 128

SEARCH RDT FM 128/32 UP/DOWN

SEARCH RDT CW 128

TRACK CLAS QDT/SL

TRACK CLAS 10 PINGS, I QDT/S



QUENCES, NON-ALERTING MODE

• • • TRACK CLASSIFY QDT/SLT — CW 4/ CW 32/ CW 4, 32 ALTERNATING

• • • • • • • • • • • TRACK CLASSIFY BURST 10 PINGS, 1 PER SECOND QDT/SLT — CW4

WEK NEL
1-10-66

4

Table 9

Coverage Performance for Tactical Situation 1

V_T		6				30			
Vos		15		20		15		20	
Classify	k \ mode	S	D	S	D	S	D	S	D
Hard	1.00	1.00	1.00	1.00	1.00	.67	1.00	.52	1.00
	1.50	1.00	1.00	.75	1.00	.51	1.00	.39	.93
	1.75	.80	1.00	.55	1.00	.37	.90	.29	.69
Easy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1.50	1.00	1.00	1.00	1.00	1.00	1.00	.83	1.00
	1.75	1.00	1.00	1.00	1.00	.81	1.00	.63	1.00

Notation:

V_T = Target speed (knots)

V_{OS} = Own Ship Speed (knots)

S = Single frequency mode

D = Dual frequency mode

K = Spacing factor; determine the amount of overlapping coverage.

Table 10

COVERAGE PERFORMANCE FOR TACTICAL SITUATIONS

K_S	Pings to Classify = 8		Pings to Classify = 20	
	Dual Mode	Single Mode	Dual Mode	Single Mode
2	1	1	1	1
2.5	1	1	1	1
3	1	1	1	1
3.5	1	1	1	1
4	1	1	1	1
5	1	1	1	1
10	1	.59	1	.57

TASK II

Task Statement

From a tactical standpoint, determine how much a ship compromises its situation by:

a. Alerting

b. Giving range

c. Giving own heading

STUDY RESULTS

	Value to Submarine Operations	
Information about the ASW Ship	Order of Importance	Why desired
Has it detected the submarine ?	1	1. To take evasive action 2. To launch a torpedo at the ASW ship or other 3. To employ a sensor not normally used (e.g., active sonar) 4. To employ countermeasures 5. To operate more openly
Range	2	1. To determine if detection by the ASW ship is likely to have occurred or to be imminent.
Course	3	1. Fleeting value throughout the submarines approach phase.

NOTES:

Range and course become critical during the attack phase . However, during this time the submarine will gather information by means of active and passive sonar and/or periscope observations.

Analysis Procedures

The results of this task were obtained through a series of interviews with officers attached to the ASW school and with active submarine commanders. The author's general impressions gathered from these interviews are summarized in this section of the memorandum. The specific details of the interviews are on file in Code 3320. The summary has been divided into three parts:

(1) An overview of the problem

(2) Interview responses to questions

(3) Specific cases in which a submarine gains information about his own detection.

THE SUBMARINE CASE

Whether a submarine is operating in a defensive or offensive manner, its CO desires and has several ways to obtain information concerning the presence of an ASW ship, the ASW ship's relative location, course, speed, equipment aboard, etc. In addition, the submarine's CO is interested in knowing what the ship knows about the presence of the submarine. Once detected, a submarine's CO has the following options:

(1) Continue with his mission

(2) Begin to evade, either to break contact or avoid an anticipated antisubmarine weapon.

(3) Release a torpedo at the ASW ship or at some other ship.

(4) Employ a countermeasure device.

(5) Employ a sensor not normally used in the situation (e.g., active sonar, radar and/or periscope).

There may also be other advantages to the submarine. For example; if submarines are operating in a closely coordinated manner, the one who feels he is detected may be more likely to use UQC to seek assistance from his companions, or at least appraise them of the situation.

It is clearly to the submarine CO's advantage to know that he has been detected at the earliest possible time. He may therefore be assumed to be alert for all indications of detection, and to maintain a continuous estimate of the likelihood that he has or will soon be detected.

Probably the most important reason the submarine wants to know range to the ASW ship is to help determine whether or not the ship has detected or is likely to detect the submarine. Range estimates obtained through observing the ship's active sonar transmissions are not likely to be used in fire control--for this the sub's solution from passive sonar is much preferred. Information from the sub's active sonar and/or periscope will also be used in fire control if it is available.

Estimation of range to ASW ship is a matter of less importance to a submarine than determination of whether the submarine has been detected.

Ship's course is of much less interest to the submarine than own-detection and range to ASW ship. A good estimate of course is only needed for fire control; prior to this time frequent destroyer maneuvers make course estimates of only fleeting value.

In a multiple ship environment the submarine's ability to obtain information is degraded becuase of the increased noise and the many pings of various pulse lengths arriving from many directions with varying intensities. Operations in a multiple ship environment has been referred to as a "symphony of pings" superimposed on a "symphony of noise." In

screen penetration operations, which will be the reference submarine's operations for the remainder of this discussion, this will generally be the case during the late approach and attack phase. Thus, although the submariner would like to know whether he is detected, he may not be able to because of the profussion of noises and the necessity of attending to attack preperations.

However, even if he is reasonably sure that he has been detected he may elect to continue his previous course of action (one cannot assume that a submarine will break off an attack just because detection may have occurred). There may be significant differences between nuclear and conventional submarines in this respect. The nuclear may be more likely to press on with their mission is spite of detection, possibly assuming their greater speed and maneuvering capabilities will get them out of trouble. Thus, in a sense, a nuclear submarine may care less about detection than a conventional submarine.

The analysis is complicated by the fact that the submarine does not have a single source of information about the surface ships' knowledge; rather it has many clues, not all of which will apply in particular situations. In addition to being able to detect changes in frequency range scale, pulse length, and time between pings, the submarine looks for changes in ship course, ship speed, use of countermeasure devices and anti-submarine torpedo noises. So, although the use of automatic non-alerting modes may block some avenue of information to the submarine, others may remain open to alert him and/or give him range. It must be noted that many of the clues the submarine ordinarily uses to determine whether he has been detected are <u>not necessarily</u> valid--a surface ship may badly deceive a sub through proper sonar operation, as is discussed later.

In outline, that is the submarine side of the problem. The sub wants to know whether he has been detected, he has several clues to determine this. Not all of the clues may be valid, some indeed may have been deliberately introduced to fool him. It will not always be possible to obtain the clues available to one-or two-ship situations when there are more ASW ships involved.

THE ASW SHIP CASE

The ship desires to detect the submarine; for this purpose he has primarily two sensors; active sonar and passive sonar. By definition, the submarine gains no information from the ship's use of passive sonar, but in his planning he must include it nevertheless. If PAIR ships are able to use active and passive sonar simultaneously we must assume that the submarine is aware of this. In active sonar operation, however, the ship has some freedom of choice. He may ping or not ping. He may vary the range scale, pulse length and other settings. He may use cursor flyback if it is available and if he feels it is warranted. He may operate his equipment in such a way as to confuse or deceive the submarine--not only can he try to deny the submarine the knowledge that he has detected the sub, but he may want an undetected sub to think that he has been detected.

The ship has a problem because he must both detect and classify the submarine, and in general the type of pulse which is best for detection is poor for classification, and conversely. Thus, in order to detect and classify as soon as possible, he must change from pulses of one type search to those more suitable to classification. We may assume that the submarine knows this, and therefore will, upon hearing this change in pulse type, assume that the change is to better classify him--he is therefore detected and hence in danger.

The ship knows that the submarine wants to know as soon as possible that he has been detected by the ship. The ship considers this information to be valuable to the submarine, and may be prepared to operate his own equipment and use tactics which are less than optimum for the express purpose of denying this information to the submarine. Just how much information the ship should give up is the issue here; it is strictly a trade-off situation which may not have a clear-cut answer. At the present the USN seldom uses the flyback feature on the SQS-23 sonar primarily because its use alerts the submarine and gives range information. Other navies (Australia and Britain) no longer use flyback either for the same reason. Other practices are also used in sonar operation which are felt to deny information to the submarine. This is evidence that the problem is indeed recognized and is acted upon by the operational forces. It appears that these practices are not based on prior analytical studies, but have instead resulted from fleet experience.

In summary, the ship's problem is this: recognizing that alerting and range information is often of importance to a submarine, to what degree (and how) should the ship degrade his own sensor performance (from the initial detection, classification, tracking and attack point of view) to attempt to deny the submarine this information?

RESPONSES TO INTERVIEW QUESTIONS

Discussions with several knowledgeable people were carried out during this PAIR study. No standard set of questions was prepared beforehand, although certain of the more important questions were asked in all cases.

1. Q. How does a submarine CO become "alerted?" How many clues does he have for this purpose and what is the relative importance of them? How accurate are the estimates of "time of alerting?"

A. There is good agreement on the possible clues, but differences in estimates of the reliability of these clues. Most thought that indication of destroyer course change, change of range scale, use of short pulses, etc., were good indications of probable detection, but they are becoming less useful as the surface ships employ more deceptive sonar operation. Regarding accuracy of estimating "time of alerting," it was not possible to get definite information.

2. Q. What difference does "alerting" (deciding that own-submarine has been detected) make in the submarine's subsequent actions?

A. Here we find considerable disagreement between the submariners interviewed . One commander felt that the submarine's CO is committed quite early and will often continue his mission; other submariners were more concerned with whether they had been detected and would base their actions on these estimates more frequently.

3. Q. What differences are there between nuclear and conventional submarines regarding the importance of and use of alerting information?

A. Alerting information is less important to a nuclear submarine since he will rely on his greater speed, endurance, and maneuverability to keep him out of trouble.

4. Q. How does a submarine estimate range to the ASW ship, and what does he do with this range? How accurate are these estimates?

Means to obtain range	Primary Utilization of Range Data	Accuracy
Passive sonar	General Requirements	fair
Active sonar	F/C	good
Periscope	F/C	excellent
Intensity Measurements	--	poor

A. Whether or not intensity could be measured by submarine instruments seemed to be a point of disagreement. This is curious because it is a matter simply of equipment availability and capability. It would appear that nobody expects a very precise estimate of range from intensity measurements.

5. Q. How important to the submarine is knowledge of the ASW ship's course?

A. Apparently not very important to anyone; changes in course are more important. No one has ever heard of trying to estimate ship's course by timing the RDT transmission. During the approach phase a base course is important, while during the attack phase the ship's instantaneous course is important; however, this will generally be obtained through periscope sightings.

6. Q. How frequent, and how effective is the use of deceptive sonar paractices (random changes in range scale, pulse length, and the like) by the surface ship?

A. There is disagreement on frequency of utilization. One commander found that random sonar operation is becoming more common. Furthermore, it is effective. The others have not encountered it frequently enough even to consider the possibility that the ship may be intentionally trying to deceive the submarine.

7. Q. To what extent does the submarine CO consider the possibility that the ship may be intentionally deceiving him through randomized sonar practices?

A. See Questions 1 and 6.

8. Q. Are there significant differences in the amount of useful information that a submarine can gain from listening to active sonar operation against ships as opposed to one or two ships?

A. There are differences in operating against one or two ships versus several ships. In a multiple ASW ship environment the background noise and many pings in the water create a very confusing picture. The effect on the submarine's operation depends on the CO. Some submariners rely on fixed rules while others "play it by ear" and thus are more responsive to a given situation.

9. Q. How often is cursor fly-back currently used in initial detection/attack situations? Does it give too much information to the submarine?

A. Use of cursor fly-back is a dead giveaway, according to everyone. The USN seldom uses this feature anymore.

10. Q. Would information from ship's sonar operation ever be of direct use in fire control?

A. No, however, it may be of indirect value in important ways, notably going active when convinced that the ship already has contact.

11. What is your opinion about the non-alerting mode concept? Are such modes needed for routine use? For occasional use? Not needed at all? Are similar ideas worth pursuing further?

A. Everyone is pleased that someone is thinking about such questions at the design stage. Most think that something like them would be desirable as an option. No one thought they would be routinely used, if available. One commander opposed them, primarily on the grounds that the submarine can't get the information anyway, so why restrict and degrade your own performance denying it to him?

12. Q. What is the need to search-while-classify?

A. There was not much discussion on this point. To the extent that it was discussed, no one seemed to doubt this need.

SPECIFIC CASES IN WHICH A SUBMARINE GAINS INFORMATION ABOUT HIS OWN DETECTION

Several kinds of information may be exploited by a submarine to gain information about his own detection and range to the ASW Ship.

1. Time between pings

A submarine can be expected to obtain the time between pings transmitted by a surface ship. From these times it is possible to determine the maximum range to which the ship is pinging, this in itself may be a help to determine whether detection has occurred. For example, if the submarine should know that the actual range is between 8 and 15,000 yards, and if the ship has been pinging at the 5,000 yard scale for some time (as determined by ping timing), the submarine can be quite sure that he has not yet been detected on active sonar.

If the ship is using cursor fly-back the submarine can tell by timing the interval between pings whether or not the ship is on one of the standard range-scales; in addition a fairly good estimate of range can be obtained, and from timing successive intervals an indication of opening, closing, or constant range can also be obtained.

As mentioned, use of cursor fly-back is considered to be such a sure sign of possible detection to the submarine that it is seldom used at present by either the USN or other navies.

2. Change in source level

Changes in source level due to change from ODT to SDT will probably not be detectable because:

a. the submarine cannot measure intensity accurately.

3. Change in pulse length

Often it is desirable to change pulse length when classifying a contact. Such changes can be detected by a submarine; the submarine usually interprets this as an indication that he has been detected.

4. Change in sonar frequency

This is only applicable when the ASW forces have the option of different kinds of sonar to perform search and classify/attack functions. (The UK uses several sonars aboard a single ship for different functions). In such cases the change to a higher frequency sonar is an indication to the submarine that an attack is imminent.

5. Change of ASW ship speed and/or course

A ship may sometimes increase speed to close a contact more quickly. Changes in ship speed are detectable by a submarine through a change in the solution for speed and course obtained by passive sonar, by changes in turn count, and by visual observation through the periscope.

A ship may be compelled to change course at contact time or while tracking a submarine in order to obtain a better fire control solution, unmask an ASROC launcher, or simply in order to maintain contact. Course changes are detectable through the passive sonar solution or by visual means. One of the main reasons a submarine comes to the periscope depth is to determine quickly any course changes by the ASW ship.

6. Weapon launch sounds

Sounds the submarine may hear from weapon launch are a rather sure indication that detection has occurred.

7. <u>Torpedo sounds</u>

Sounds from anti-submarine torpedoes, either radiated noise or torpedo pinging, are indications of detection.

8. <u>ASW force tactics</u>

Joint observations on pairs of ships may yield information that single-ship observations would not. For example, if two ships are both closing the submarine he may be more likely to assume that he has been detected than if only one is closing.

9. <u>Signal arrivals</u>

A method known as "ping stealing" can sometimes be used to get an estimate of range, and perhaps from this an estimate of own-submarine being detected. One calculates the difference in arrival times of a surface ship ping via two different paths--direct path and bottom bounce. This method can only be used at longer ranges (say, greater than 15 or 20 kiloyards) and is never very accurate.

10. <u>Signal intensity</u>

At present US submarines do not obtain good estimates of range to the echo-ranging ship through the use of signal intensity as indicated by sonar intercept equipment. This is due both to the inadequacies of the intercept equipment, the imperfect knowledge of local environmental conditions, and to our inadequate knowledge of propagation. Rough estimates of range may be made by intensity, either as recorded by an instrument or "measured" subjectively.

11. Signal reverberation content

A standard submarine tactical publication outlines a method "currently under evaluation." This procedure consists of measuring (at the submarine) reverberation from the reciprocal bearing of the ship. When the ship is close enough this reverberation can be observed, otherwise it cannot. This gives a rough estimate of range, and hence of likelihood of detection of own-submarine.

12. Passive sonar

The submarine is continuously (unless he is at high speed) using passive sonar information to estimate speed, course, and range to the ASW ship. Since submariners use this generated information in fire control in preference to that derived by the methods just discussed, the best range estimates are available from this source. Estimation of range enables an estimate of likelihood of own-submarine detection to be made.

TASK III

Task Statement

Analyze the ability of PAIR to interface properly with ASROC (Mk 111 and Mk 114) when in the non-alerting modes, i.e., adequate data rates, tracking accuracies, etc.

STUDY RESULTS

Mode of transmission \ Target Track	Constant Velocity	Maneuvering
Single Frequency Mode	acceptable	Marginal
Dual Frequency Mode	acceptable	acceptable

NOTE:

The indicated results were obtained by comparing the two automatic non-alerting transmission modes to conventional (manual) modes of operation.

Dual Frequency Mode

The dual frequency mode of operation should be adequate, since, if anything, it should enhance the data rate. The search keying interval would be set to the range scale just beyond the sonar range of the day and the track and classification (T/C) range scale setting would generally be one setting lower than the search setting.

Single Frequency Mode

The single frequency mode of transmission would degrade the tracking performance of the Mk 111 and Mk 114 weapon systems. The degration is prevalent in cases of:

1. Large observation errors and/or

2. Maneuvering targets.

In situations where the observation errors are small and the target is proceeding with a constant velocity vector the mode should generally prove adequate.

Analysis Procedures

The analysis provided for in this task is of a qualitative nature. The results are inferred from other studies.

ATTACK CONSOLE MK-53

The target course solution of the manually operated Mk 53 is an "eyeball least squares" and is obtained usually by an operator using a cursor. Target speed solutions are obtained by aligning a "speed shadow" with either the end or fourth point depending on whether end-point or 4-point speed solutions are desired.

Reference 3 indicates that the 4-point tracking process performed by the operator using the Mk-53.

(1)

$$C_T \quad \tan^{-1} \frac{(X_n - X_{n-3}) + 1/3\,(X_{n-1} - X_{n-z})}{(Y_n - Y_{n-3}) + 1/3\,(Y_n - Y_{n-z})}$$

$$S_T = \frac{[\,(X_n - X_{n-3})^2 + (Y_n - Y_{n-3})^2]^{\frac{1}{2}}}{t_n - t_{n-z}}$$

where:

C_T, S_T = the targets present estimated course and speed respectively.

X_n, Y_n = The targets X and Y coordinate position respectively, at the time of the nth ping.

t_n = The time of the nth ping

These estimated courses and speeds are used to update the targets position until the next data point is received. The accuracy of the prediction then is a function of:

a. How good the estimates of C_T and S_T are at time n, and

b. What the target does in the interval between t_n and t_{n+1}

The behavior of the tracking function under the dual frequency mode is similar to current operations in that a relatively constant data rate is maintained. However, in the single frequency mode a gap, which varies between 3.125 and 37.5 seconds exists between T/C ping sequences. This gives the target considerable time to maneuver at the higher search range scale settings (Table 11). These gaps have the following affect on the tracking system:

1. Because of the gap between the T/C ping sequences more time is required to establish a track.

2. The increased time between tracking signals at the gap introduces heavier smoothing then may be desired and thus decreases the responsiveness of the system.

Table 11

TARGET TRAVEL AS A FUNCTION CAPTINE

AND MOTION PARAMETERS

Distance Traveled By Targets (Yards)

Sub. Speed / Time of the gap (seconds)	6 knots	12 knots	18 knots	30 knots
	3.336 y/s	6.672 y/s	10.008 y/s	11.12 y/s
62.5	208.5	417	625.50	695
37.5	125.1	250.2	375.30	417
25	83.40	166.80	250.20	278
6.25	20.85	41.70	62.55	69.5
3.125	10.425	20.85	31.275	34.750

Angle Turned Through During the Gap (Degrees)

Sub. Turning Rate / Time of the gap (seconds)	1°	3°	6°
62.5	62.5°	187.5	37.5
37.5	37.5	112.5	22.5
25	25	75.0	150
6.25	6.25	18.75	37.50
3.125	3.125	9.375	18.75

TASK IV

Task Statement

Determine minimum spacing of ships with PAIR.

Study Results

Minimum ship spacing is equal to a spacing factor of 1.5 times the below-layer detection range.

$$(1)\quad S_M = (K_S)\ (R_D)$$
$$= (1.5)\ (1.8) = 2.70 \text{ kyd}$$

The below layer detection range is conservative and will probably be of the order of 3 kyd, which would result in a spacing of 4.5 kyd.

Analysis Procedures

The task of specifying a minimum ship spacing is complicated by the many variables involved. However, by restricting the ASW operations to "worst case" models some insight into the problem can be achieved.

In Task 1, models were developed for calculating the operational effectiveness of the PAIR non-alerting modes. In that study it was found for Model 1 (overlapping sonar coverage) that for a spacing factor of 1.5 the coverage performance of the dual mode is above .90 in all cases (Table 9).

Thus, under the specified conditions, for K_S = 1.5 sufficient time is available to cope with most tactical situations.

Another aspect of the problem worthy of comment is the effect of R_D and ship spacing on the probability of contact. Reference 4 defines the relationship between sonar coverage factor (C), sweep width (W), and ship spacing (S):

$$(2)\quad C = \frac{W}{S}$$

Letting

$$(3) \quad W = 2R_D$$

and

$$(4) \quad S = K_S R_D$$

Results in

$$(5) \quad C \doteq \frac{2}{K_S}$$

For $K_S = 1.5$ $C = 1.33$

Figure 9, taken from reference 4, shows that for $K_S = 1.5$ a high probability of contact by the ASW ship is attained.

NOTES:

1. GOOD applies to detection of large targets, including surfaced submarines.
2. GOOD applies also to detection of small targets in low Sea States (less than 2).
3. POOR applies to small targets such as a snort or lift raft in high Sea States (over 3).
4. Intermediate values between GOOD and POOR apply to small targets in Sea States 2 and 3.

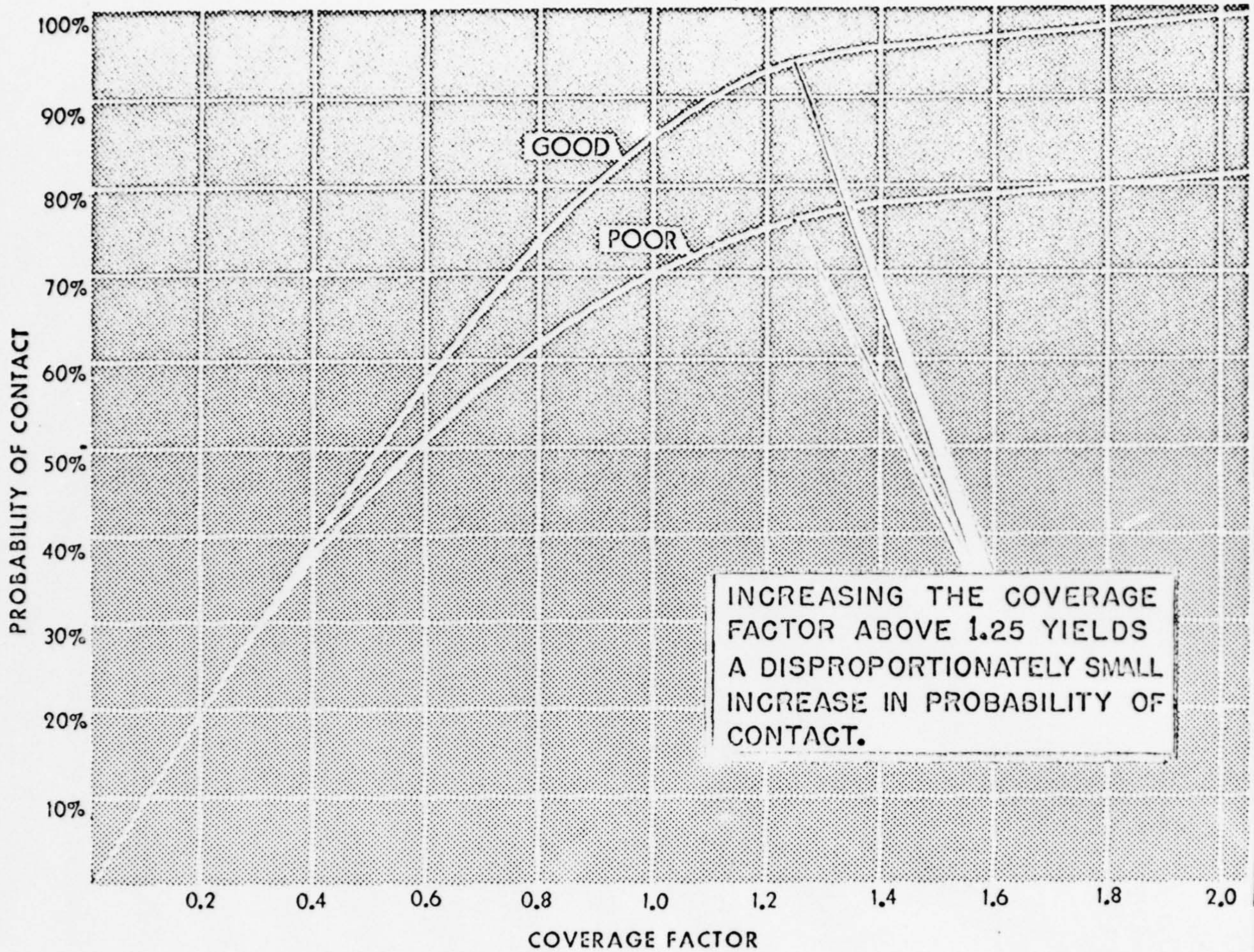


Figure 9 Probability of Detecting a Submarine Penetrating Between adjacent ASW Ships

REFERENCES

1. J.T. McKinney, Underwater Ordnance Department, NOTS Pasadena NOTS/IDP 2250, Phase I, Integrated Combat System Weapon Subsystems Simulation Analysis for Sea Hawk: Digital Computer Mathematics (U), 15 January 1965.

2. NEL Letter Report; Confidential, AN/SQS-23 Sonar Letter Report Addendum, Serial 2140-017 USNEL, 24 November 1965

3. C.H. Sturtevant, E.S. Nizyborski, E. Lee, L. A. Harvey, NEL Technical Memorandum 896, Secret, Mission/Geographic area Considerations for Modeling ASW Operations of the 1968 to 1975 Time Period (U), 1 November 1965

4. Confidential; Chief of Naval Operations ATP1(A) Volume 1, Allied Naval Maneuvering Instructions (U), 1961